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MEDIUM WAVE BAND INFRARED IMAGING SYSTEMS AND THEIR APPLICATIONS

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# I. INTRODUCTION

As far as 3 - 5 micron and 8 - 12 micron wave band infrared imagery technology is concerned, it has been a key point in the development of infrared imagery technology outside China all along. Comparing these two wave bands, which wave band has superior performance in the area of long distance detection? Beginning in the 1970's and right through the discussions [2,3,4], with analytical articles still being published in 1991 [1], it is possible to see the importance of researching this question. During discussions for 20 years, various authors-- because of postulated conditions--opted for the use of data which, despite the fact that they were the same, gave conclusions which were different. Also, because the requirements of users are different, directions for the key points of development and application are also different. Following along with progress in relevant technologies, the development of detection device technologies is recognized to be in the process of ceaseless intensification. In 1991, James put forward--speaking in terms of background temperatures of 230 K or above--conclusions that 3 - 5 micron wave bands are superior to 8 - 12 micron wave bands. Then, speaking in terms of the current levels of development of the two types of systems, this point has already been verified. Due to good atmospheric transmission characteristics, system sensitivities being high (referring to fixed observation systems), prices being low, and such factors as the contrast between targets and background radiation, 3 - 5 micron infrared imaging systems have achieved rapid development and applications in the last 10 years. On the basis of

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* Numbers in margins indicate foreign pagination. Commas in numbers indicate decimals.

incomplete statistics, at the present time, the various key nations of the world have already applied 3 - 5 micron infrared imagery systems and are in the midst of developing over 50 types of applications in the areas of observation, measurement, monitoring, alignment, tracking, guidance, alarms, and so on.

This article makes only a simple introduction of the status of developments and applications associated with 3 - 5 micron wave band infrared imaging technology outside China. Concise analysis and comparisons are carried out on its performance, discussing the situations and causes giving precedence to an option for the use of 3 - 5 micron infrared imagery.

## II. A GENERAL DISCUSSION OF THE STATE OF 3 - 5 MICRON WAVE BAND IMAGERY SYSTEM APPLICATIONS OUTSIDE CHINA

As far as 3 - 5 micron wave band imagery systems are concerned, from the X ray scanning methods of the 1970's, they have already developed into fixed gaze imaging systems. At the present time, 64x64 element, 128x128 element, 248x248 element, and 512x512 element fixed gaze imaging systems have all already been developed. Moreover, applications have been achieved. Among these, 128x128 element performance is good. The NETD reaches 0.001K. Costs are low--only several tens of thousands of U.S. dollars a unit. InSb 128x128 element system NETD associated with the U.S. Amber engineering company and photoelectric companies have all reached 0.001K. PtSi ones are capable of reaching 0.01 - 0.03K. In the latter part of the 1980's, there was a turn from X ray machine scanning systems to fixed gaze systems. Table 1 gives part of the 3 - 5 micron imagery systems which have already been developed in the world and are in the

midst of application. From the table, it can be seen that the principal directions of applications are:

1. Search, warning, and monitoring systems used on the ground and on warships--for example, the VAMPIRML infrared warning system developed cooperatively by the French CSEE and EAT companies as well as the SPIRAL panoramic search and warning system developed by the SAGEM company. The effective distance is 10 - 15 km. The IRSCAN infrared search sensors of the Dutch Phillips company all opt for the use of the two 3 - 5 micron and 8 - 12 micron wave bands. Italy's SIR-8 system and Israel's DS- 35 system both opt for the use of 3 - 5 micron wave bands.

2. Systems used in observation and alignment are relatively numerous, as shown in Table 1.

3. Use in the 6 types of infrared homing head systems set out in the Table. They are, respectively the tank destroyer (Assault Breaker) developed in combination by the U.S. and West Germany, that is, the SADARM antitank missile; the U.S. AGM-- 114A (Hellfire) missile; the AGM--84A improved model Bulywe (phonetic) antiship missile; Tomahawk antiship missiles; and, ALM-9X air to air missiles.

4. Use in airborne search and warning systems.

Defending against infrared missile attacks has already become an important point in aircraft defense. During the Gulf War, in the total number of aircraft lost by the U.S., 90% were shot down by infrared missiles. As a result, this application is an important point of development in the 1990's--like the Fyseye system of the U.S. General Electric company or the U.S. Air Force Altair, developed by the Phillips company. Besides this, there are also applications

in the fields of antimissile systems, satellite remote sensing, aerial reconnaissance, and so on.

In the 1990's, the U.S. will continue to strengthen imagery technology in the 3 - 5 micron wave band as well as work on its applications and development. Among the key technology project items of the U.S. Defense Department (1992), there are many places which put forward continuing development of medium wave infrared imagery (focal plane) technology. For example, among electronic device projects, there are discussions of focal plane array technology: "Focal plane (FPA) scanning systems are used in shipborne infrared search and tracking (IRST) systems, airborne infrared search and tracking systems, forward looking infrared, and navigation systems. Fixed view arrays can satisfy the requirements of missile guidance heads, missile alarms, as well as space monitoring. There are broad uses in the areas of non (deep) cooling arrays in weapons alignment, missile guidance heads, as well as operator observation devices." For example, among relationships to photoelectronic instrument technology and the propulsion field, one lists:

(1) In the field of global monitoring and communications, two dimensional tellurium-cadmium-mercury and indium antimonide adulterated silicon focal plane array technology targets;

(2) In air supremacy and area defense, there is listed a single plate medium wave tellurium-cadmium-mercury focal surface array (1x1) (medium wave/long wave) dual color fixed view focal plane array technology target;

Table 1  3 - 5  Micron Partial Infrared Imagery System

| (1) 序号 | (2) 名称型号 (a) | 工作波段 (3) ($\mu$m) | 空间分辨率 (4) (mrad) | 噪音等效温差 (5) $NETD$ (K) | (6) 用途 (b) | 生产(研制)厂家 (7) (c) |
|---|---|---|---|---|---|---|
| 1 | 355 型仪象仪 | 3~5/8~12 | 1.3×1.6 | 0.12/0.4 | 坦克观测 | 美国 Kollmorgam 公司 |
| 2 | TWS 热象瞄准具 | 3~5 | 1 | 0.4 | 多用途瞄准 | 美国 Magnavox 公司 |
| 3 | LT106 平持热象仪 | 3~5 | 2.3 | 0.3 | 火炮监视瞄准 | 英国 Lasengage 公司 |
| 4 | MEL 平持热象仪 | 3~5 | 1 | 0.2 | 地面观测 | 英国 MET Eguipment 公司 |
| 5 | CTRTEVS 型红外电视 | 3~5/8~12 | | 0.5 | | 意 光学机械(CMI)公司 |
| 6 | IRGO 红外眼 | 3~5 | 0.57 | 0.2 | 监视观察 | 法国 SAT 公司 |
| 7 | TD22 型热象仪 | 3~5 | | | 观测 | 以色列 Rafael 公司 |
| 8 | TD42 型热象仪 | 3~5 | 0.5 | 0.15 | 观测 | 以色列 Rafael 公司 |

(a)↓ 表 1(续) (b)↓ (c)↓

| | | | | | | |
|---|---|---|---|---|---|---|
| 9 | Thermorision | 3~5 | 2 | | | 瑞典 AGEMA 公司 |
| 10 | TISA 热象仪 | 3~5 | 0.5/0.2 | 0.2 | 警戒 | 瑞士 Siemens Albis 公司 |
| 11 | WBG39 热象仪 | 3~5 | 0.3 | 0.2 | | 瑞士 Siemens Albis 公司 |
| 12 | Pirana 红外跟踪仪 | 3~5 | | | | 法国 SAT 公司 |
| 13 | Vampir 全景搜索系统 | 3~5/8~12 | 0.3 | | 舰载搜索 | 法国 SAT 公司 |
| 14 | TOTM 火控系统 | 3~5 | | | | 法国 CSEE 公司 |
| 15 | IRSCAN | 3~5/8~12 | 0.5 | | 搜索 | 荷兰信号公司 |
| 16 | DS-35 | 3~5 | | | | 以色列光电公司 |
| 17 | CYClope | 3~5 | | 0.28 | 侦察系统 | 法国SAT 公司 |
| 18 | Supercyclope | 3~5/8~12 | 1.2 | 0.3 | 侦察、搜索 | 法国SAT 公司 |
| 19 | SIRERAC 红外前视 | 3~5 | 0.35 | | | 德国西门子公司 |
| 20 | RZ50 型热象仪 | 3~5 | 0.5 | | | 法国 Eltro 公司 |
| 21 | VIR52 | 3~5 | | | | 意 OfficineClihe 公司 |
| 22 | AGM114A Hellfiro 导引头 | | | | 空对地制导 | 美国麦道公司、休斯公司 |
| 23 | AGM84A 改进型导引头 | 3~5 | | | 反舰导弹制导 | 美国麦道公司、休斯公司 |
| 24 | 战斧反舰导弹导引头 | 3~5 | | | 反舰导弹制导 | 美国麦道公司、休斯公司 |
| 25 | TamkBreaker 导引头 | 3~5 | | | 反坦克导弹制导 | 美国罗克威尔 Honeywell |
| 26 | AsSantBreaker 导引头 | 3~5 | | | 反坦克导弹制导 | 美国罗克威尔 Honeywell |
| 27 | AIM-9X 导弹导引头 | 3~5 | | | 空空导弹 | 美国休斯公司 |
| 28 | 舰载 2RST 系统 | 3~5/8~12 | | | 舰空搜索 | 英国托恩公司 |
| 29 | FlySeye | 3~5 | | | 机载告警 | |
| 30 | 机载 2RSTS | 3~5 | | | 机载告警 | 美国通用电器公司 |
| 31 | E14P 搜索跟踪器 | 3~5 | | 0.01 | 机载告警 | 美国通用电器公司 |
| 32 | AN/SAR-8 2RST 系统 | 3~5 | | | 警戒瞄准 | |
| 33 | PITONE | 3~5/8~12 | | | 舰载监视 | 意大利塞来尼亚电子公司 |
| 34 | SIR-3 | 3~5 | 0.5 | | 舰载监视 | 意大利塞来尼亚电子公司 |
| 35 | SPLRAL 系统 | 3~5/8~12 | 0.45 | | 舰对空 | 法国通用电器设备公司 |
| 36 | AlTair | 3~5 | | | 机载目标探测 | 美国空军菲利浦公司 |
| 37 | AE4256 热象仪 | 3~5 | | 0.01 | | 美国 Amber 工程公司 |
| 38 | AE 128 热象仪 | 3~5 | | 0.01 | | 美国 Amber 工程公司 |
| 39 | IRC-160 | 3~5 | | 0.025 | | 美国光电子公司 |
| 40 | IRC160ST | 3~5 | | 0.001 | | 美国光电子公司 |
| 41 | $V_2$-128 | 3~5 | | 0.001 | | 美国光电子公司 |
| 42 | $V_2$-160×120 | 3~5 | | 0.001 | | 美国光电子公司 |
| 43 | 870 热象仪 | 3~5 | | 0.1 | | 日本三菱公司 |
| 44 | 2RM-500 | 3~5 | 0.5 | | | 日本三菱公司 |
| 45 | 2R5120 | 3~5 | 0.5 | 0.15 | | 日本三菱公司 |

(1) Serial No. (2) Nomenclature Model (3) Operating Wave Band (4) Spacial Resolution (5) Noise Effective Temperature Difference (6) Use (7) Production (Development) Plant 1(a) 355 Model Image Instrument 1(b) Tank Observation 1(c) U.S. Kollmorgam Co. 2(a) Thermal Image Sight 2(b) Multiple Uses in Aiming 2(c) U.S. Magnavox Co. 3(a) LT106 Horizontal Thermal Imaging System 3(b) Gun Monitoring and Aiming 3(c) U.K. Lasengage Co. 4(a) MEL Horizontal Thermal Imaging System 4(b) Ground Observation 4(c) U.K. MET Equipment Co. 5(a) CTRTEVS Model Infrared Television 5(c) Italian CMI Co. 6(a) IRGO Infrared Eye 6(b) Monitoring and Observation 6(c) French SAT Co. 7(a) TD22 Model Thermal Imaging System 7(b) Observation 7(c) Israeli Rafael Co. 8(a) TD42 Model Thermal Imaging System 8(b) Observation 8(c) Israeli Rafael Co. 9(c) Swedish AGEMA Co. 10(a) TISA Thermal Imaging System 10(b) /3 Warning 10(c) Swiss Siemens Albis Co. 11(a) WBG39 Thermal Imaging System 11(c) Swiss Siemens Albis Co. 12(a) Pirana Infrared Tracking System 12(c) French SAT Co. 13(a) Vampir Panoramic Search System 13(b) Shipborne Search 13(c) French SAT Co. 14(a) TOTM Fire Control System 14(c) French CSEE Co. 15(b) Search 15(c) Dutch Communications Co. 16(c) Israeli Photoelectric Co. 17(b) Reconnaissance System 17(c) French SAT Co. 18(b) Reconnaissance and Search 18(c) French SAT Co. 19(a) SIRERAC Forward Looking Infrared 19(c) German Siemens Co. 20(a) RZ50 Model Thermal Imaging System 20(c) French Eltro Co. 21(c) Italian Officine Clihe Co. 22(a) AGM114A Hellfire Missile Head 22(b) Air to Ground Guidance 22(c) U.S. McDonald Douglas Co., Hughes Co. 23(a) AGM84A Improved Model Missile Head 23(b) Antiship Missile Guidance 23(c) U.S. McDonell Douglas Co., Hughes Co. 24(a) Tomahawk Antiship Missile Guidance Head 24(b) Antiship Missile Guidance 24(c) U.S. McDonald Douglas Co., Hughes Co. 25(a) TankBreaker Guidance Head 25(b) Antitank Missile Guidance 25(c) U.S. Rockwell Honeywell 26(a) AsSantBreaker Guidance Head 26(b) Antitank Missile Guidance 26(c) U.S. Rockwell Honeywell 27(a) AIM-9X Missile Guidance Head 27(b) Air to Air Guidance 27(c) U.S. Hughes Co. 28(a) Shipborne 2RST System 28(b) Shipborne Air Search 28(c) U.K. Tuoen (phonetic) Co. 29(b) Airborne Warning 30(a) Airborne 2RSTS 30(b) Airborne Warning 30(c) U.S. General Electric Co. 31(a) E14P Search and Tracking Device 31(b) Airborne Warning 31(c) U.S. General Electric Co. 32(a) AN/SAR-8 2RST System 32(b) Warning and Aiming 33(b) Shipborne Monitoring 33(c) Italy's Sailainiya (phonetic) Electronics Co. 34(b) Shipborne Monitoring 34(c) Italy's Sailainiya (phonetic) Electronics Co. 35(a) SPLRAL System 35(b) Ship to Air 35(c) French General Electric Equipment Co. 36(b) Airborne Target Detection 36(c) The U.S. Air Force Phillips Co. 37(a) AE4256 Thermal Imaging System

37(c) U.S. Amber Engineering Co. 38(a) AE 128 Thermal Imaging System 38(c) U.S. Amber Engineering Co. 39(c) - 42(c) U.S. Photoelectronic Co. 43(a) 870 Thermal Imaging System 43(c) - 45(c) Japan's Mitsubishi Co.

/4

3) In the field of advanced ground combat, there are listed uses in alignment monitoring, sensors, missile tracking, as well as military applications of noncooled (deep cooled) infrared focal plane arrays (including 3 - 5 microns). In area of channels for photoelectronic device technology targets, the possibility of producing medium wave large scale infrared detection arrays will be empirically verified before 1995. Medium wave focal plane arrays 25.4mmx25.4mm (1x1in) are handed over for use, and so on. From this, it can be seen that, despite the fact that 3 - 5 micron focal plane systems are relatively mature, before and after 1995, the U.S. will still continue developing medium wave infrared imagery technology.

## III. PERFORMANCE COMPARISONS OF 3 - 5 MICRON AND 8 - 12 MICRON WAVE BAND APPLICATIONS

As far as the two wave bands are concerned, which one has superior performance in long range detection? A relatively scientific answer is that this depends primarily on such things as radiation characteristics of detected targets, performance levels of detection devices, atmospheric transmission properties, as well as methods of application, and so on.

## (I) Basic Models for Comparisons of Relative Performance

Following along with progress in the development of detection technology as well as related technologies and unceasing changes in knowledge about problems, comparative results are also in the process of constant change. However, the basic thinking and methods associated with analyses are roughly consistent. Formulae which are adopted for use are basically the same. For the sake of simplicity and convenience, we cite here the forms of Thomas W. Tuer and others to act as the basis for analysis.

The basic expression reflecting system performance is:

(1)

$$R'_{\Delta d} = K\eta \cdot \eta_d^{\frac{1}{2}} \cdot R_{\Delta t}$$

In the equation

K --a constant. Speaking with regard to photoconducting detection devices, it is 1. In the case of light fluctuation detection devices, it is $2^{\frac{1}{2}}$ ;

$\eta$ --quantum efficiency;

$\eta_d$ --parameters relating to detection devices;

$R_{\Delta t}$ --radiation function;
The expression is:

(2)

$$R_{\Delta t} 1/2(2hc)^{\frac{1}{2}} \frac{\int_0^{\infty} T_1(\lambda)\cdot T_a(\lambda)\cdot \frac{\partial^2 J_t}{\partial T \partial \lambda}(\lambda) d\lambda}{\left[\int_0^{\infty} T_1(\lambda) \frac{\partial I_b^{*}}{\partial \lambda}(\lambda) d\lambda\right]^{\frac{1}{2}}}$$

In the equation

$T_1(\lambda)$— --optical system and light filter plate transmission coefficients;

$T_a(\lambda)$— --atmospheric transmission coefficients;

$J_t$— --target radiation flux density (or) radiation strength;

$L_b^*$— --background radiation flux density;

$\bar{T}$— --temperature;

$\lambda$— --wavelength.

Here, it is assumed that molecules in background limit detection device $R_{\Delta t}$ represent target equivalent temperatures and background temperatures. There are measurements of tiny differential signals. For the sake of convenient analysis and comparison, when use is made of forms (1) and (2) for analysis, the following assumptions are made:

(1) Targets and backgrounds are both black bodies. Background temperatures are approximately 300K.

(2) Target temperatures are higher than the background by a constant value $\Delta T$. In calculations, this is taken as 1K.

(3) Detection devices are background limit probes. /5

All authors opt for the use of basically the same formulae. Only in the consideration of the selection of background limits and non background limits, atmospheric transmission models, optical modulation transmission functions, as well as their related data are there differences--for example, Milton opts for the use of atmospheric model Latrine, but Tuer opts for the use of LowtranIIIb, and reference [4] selects the use of Lowtran6. Wave band boundary data are different. There are 8.1 - 12.2 microns, 8 - 12 microns, 8.13 - 12.2 microns, and 3.4 - 5.1 microns, 3 - 4 - 4.8 microns, 3.4 - 4.1 microns, 3 - 5 microns, and so on, and so on. These reflect differences in numerical values. However, they opt in common for the use of the concept of relative signal to noise ratios. The expression is:

(3)

$$SNR_{rel}(\Delta\lambda) = \frac{R_{\Delta t}(\Delta\lambda)}{R_{\Delta t}(8\sim 12\mu m)} \cdot \zeta$$

In the equation,

$R_{\Delta t}(\Delta\lambda)$——--radiation function associated with a certain wave band;

$R_{\Delta t}$ (8-12 microns) -- 8 - 12 micron wave band radiation function;

$\zeta$—— --considering optical modulation transmission functions, coefficients associated with such factors as detection device related parameters, and so on.

Use is made of $SNR_{erl}(\Delta\lambda)$ in order to express relative performance comparisons of the two wave bands.

$SNR_{erl}(\Delta\lambda) > 1$ is explained by $\Delta\lambda$ wave band performance better than the performance of 8 - 12 microns. $SNR_{erl}(\Delta\lambda) < 1$ is, then, the opposite of this.

Obviously, due to the influences of atmospheric factors, this specific value is a function of distance. They respectively give curves under various types of conditions using distances as horizontal coordinates and $SNR_{crl}(\Delta\lambda)$ as vertical coordinates.

In 1991, the conclusions James put forward did not consider atmospheric influences. They only considered target temperature and gave curves varying with target temperature.

(II) Basic Data Associated with Radiation in the Two Wave Bands

(1) Comparison of Derivatives [12] Associated with Black Body Surface Radiation as Well as the Relevant Temperatures:

| (1) 辐射密度 $(W/cm^2)$ $W$ | 温(2)度 | (3) 波段 | | (4) 比值 |
|---|---|---|---|---|
| | | $3\sim5\mu m$ | $8\sim12\mu m$ | $\beta_0$ $(3\sim5\mu m)/(8\sim12\mu m)$ |
| | 300K | $1.873\times10^{-4}$ | $3.852\times10^{-8}$ | 1/20.6 |
| | 400K | $28.411\times10^{-4}$ | $14.231\times10^{-8}$ | 1/5 |
| | 500K | $167.7\times10^{-4}$ | $28.95\times10^{-8}$ | 1/1.7 |
| (5) 辐射密度对温度的导数 $\partial\omega/\pi\partial T$ | | | | $\beta_1$ |
| | 300K | $0.679\times10^{-5}$ | $0.63\times10^{-4}$ | 1/9.3 |
| | 400K | $6.35\times10^{-5}$ | $1.27\times10^{-4}$ | 1/2.0 |
| | 500K | $23.5\times10^{-5}$ | $1.38\times10^{-4}$ | 1/0.78 |

(1) Radiation Density (2) Temperature (3) Wave Band (4) Specific Value (5) Derivative of Radiation Density Versus Temperature

(2) Comparisons of Contrast and Background Limit Signal to Noise Ratios (Assume ΔT=1k):

| (1) 对比度 $\frac{\partial\omega}{\pi\partial T}\cdot\frac{\Delta T}{\omega^{1/2}}$ | 温(2)度 | (3) 波段 | | (4) 比值 |
|---|---|---|---|---|
| | | 3～5μm | 8～12μm | $\beta_2$ (3～5μm) / (8～12μm) |
| | 300K | 0.036 | 0.016 | 2.25 |
| | 400K | 0.023 | 0.019 | 2.5 |
| | 500K | 0.014 | 0.006 | 2.3 |
| (5) 背景限信噪比 $\frac{\partial\omega}{\partial T}\cdot\frac{\Delta T}{\omega^{1/2}}$ | 300K | $0.5\times10^{-8}$ | $1\times10^{-8}$ | $\beta_4$ 0.5 |
| | 400K | $1.2\times10^{-8}$ | $0.106\times10^{-8}$ | 12 |
| | 500K | $5\times10^{-8}$ | $0.08\times10^{-8}$ | 62 |

(1) Contrast (2) Temperature (3) Wave Band (4) Specific Value (5) Background Limit Signal to Noise Ratio

(3) Comparison of Relative Signal to Noise Ratios $SNR_{rel}(\Delta\lambda)$ /6 When 300K Target Background Distances Are 0km (When Consideration Is Not Given to Optical Modulation Transmission Functions):

| (1) 波段 $\Delta\lambda$ | $SNR_{rel}(\Delta\lambda)$ |
|---|---|
| 8～12μm | 1 |
| 3～5μm | 0.5 |
| 3.4～5μm | 0.342 |
| 3.4～4.1μm | 0.147 |

(1) Wave Band

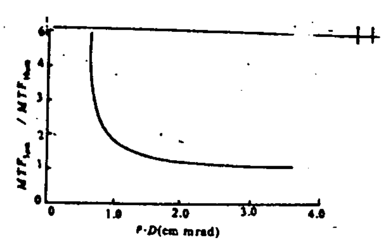

Fig.1 Ratio of Diffractive Optical Modulation Transmission Functions

## (III) Other Relevant Data

(1) As far as optical modulation transmission functions are concerned, Tuer gives $\zeta = \quad = 1.77 - 2.83$ and Milton is similar. Curves comparing the two wave bands in terms of the correlations between the ones Milton gives and relevant parameters are as shown in Fig.1. Fig.1 represents the ratio of two wave band diffractive limit optical modulation transmission functions (MTF). In the Fig., MTF is the function ρD. Here, ρ is the width of the spread angle corresponding to the target in the test imagery. D is the aperture (diameter) associated with refractive optical systems.

(2) Comparisons of Detection Device D* Values

a) 300K background limit D* value ratios are $D^*_{3.5\mu m} / D^*_{10\mu m} > 10^{(n)}$ ;

b) As far as current FPR detection devices are concerned, due to the fact that 3 - 5 micron wave bands opting for the use of semiconductor band gaps which must be narrower than 8 - 12 micron wave bands, 3 - 5 micron background radiation is small. Therefore, background noise and noise given rise to by tunnel effects, as well as thermal noise are all small. It is easy to realize background limitations. By contrast, the noises discussed above associated with 8 - 12 micron IRCCD obviously increase. Moreover, restraining the problem makes difficulties for background limit devices. Therefore, in actual systems, 3 - 5 micron sensitivities are higher than 8 - 12 microns. As the James article points out, when the influences of atmospheric transmission are not considered, and when it is given that targets are at temperatures of 230K or above, the performance of 3 - 5 microns is better

than 8 - 12 microns. (3)

Atmospheric Transmission Data

From Fig.2 and Fig.3, it is possible to see that, under the conditions of tropical atmospheric models, the highest points on 8 - 12 micron wave band 10km penetration rate curves are at 50% or below. However, the highest points for 3 - 5 microns are 42%.

For conditions of 23.3°C temperature, relative humidity of 82%, and visibility of 22km, Fig.4 gives an approximate average penetration rate of 36%. However, under the same conditions, 8 - 12 micron average penetration curve values are under 5%. These conditions are equivalent to normal weather in the middle latitudes.

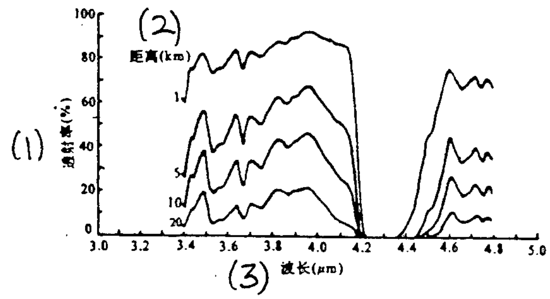


Fig.2 Various Types of 3 - 5 Micron Distance Atmospheric Penetration Rate Curves Calculated by Tuer Using Tropical Atmospheric Models Under Conditions of 8.5km Visibility and 0.75km Altitude (1) Penetration Rate (2) Distance (3) Wave Length

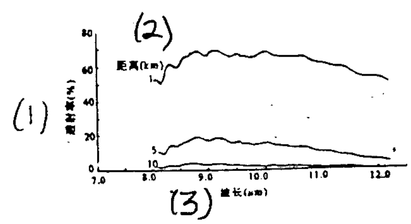


Fig.3 Various Types of 8 - 12 Micron Distance Atmospheric Penetration Rate Curves Calculated by Tuer Using Tropical Atmospheric Models Under Conditions of 8.5km Visibility and 0.75km Altitude (1) Penetration Rate (2) Distance (3) Wave Length

/7

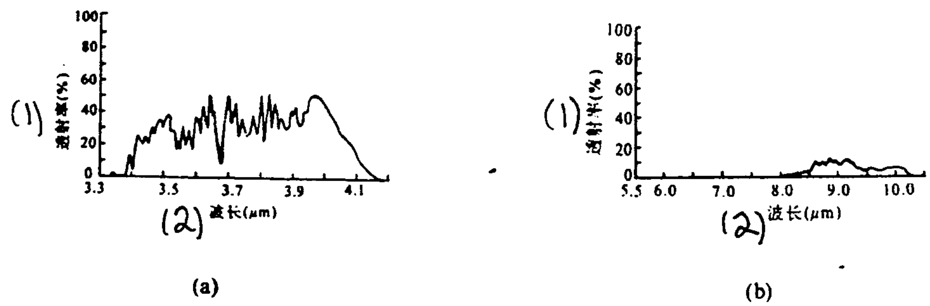


Fig.4 Atmospheric Penetration Curves from Actual Atlantic Measurements (a) (1) Penetration Rate (2) Wave Length (b) (1) Penetration Rate (2) Wave Length

(IV) Relative Performance Comparison Results

(1) Classical True Comparison Result Curves and Corresponding Conditions

Fig.5 gives the atmospheric model as Latrine, the wave bands selected for use as 3.4 - 4.8 microns and 8.1 - 12.2 microns and the visibility as 8.5km as used in comparative curves of relative performance.

In the Fig., curves are given for different altitudes. From Fig.5, it is possible to see that the performance of the two winter wave bands approaches the summer 3.4 - 4.8 microns and are better than 8.1 - 12.2 microns. Tropical weather medium wave bands are even better than long wave bands.

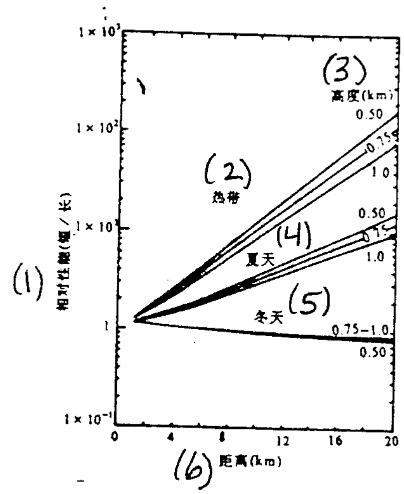


Fig.5 Relative Performance Comparisons of 3.4 - 4.8 Microns and 8.1 - 12.2 Microns (1) Relative Performance (Short/Long) (2) Tropics (3) Altitude (4) Summer (5) Winter (6) Distance

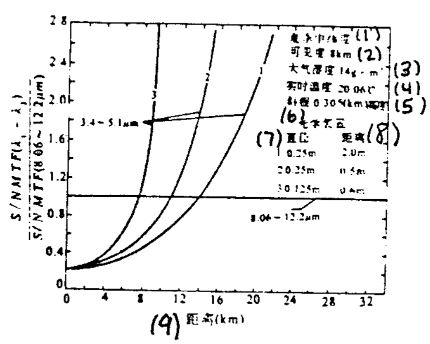


Fig.6 Specific Value Curves for Relative Signal to Noise Ratios (1) Summer Middle Latitudes (2) Visibility (3) Atmospheric Humidity (4) Real Time Temperature (5) Diagonal Travel (6) Optical (illegible) (7) Diameter (8) Distance (9) Distance

(2) Classical Curves and Relative Conditions Compared by Milton

Fig.6 is a curve Milton gives for relative performance comparison. In the Fig., the indicated conditions are: visibility 8km, humidity 14g/m2 , temperature 20.02°C, altitude 0.305km. In the Fig., the three curves correspond respectively to the sizes of three types of apertures and targets.

From the Fig., one can see that, for short range horizontal operating distances, that is, 6km or less, 8.06 - 12.2 microns is better than 3.4 - 5.1 microns. However, outside 6km, the opposite is true.

(3) As far as Findlay's comparison curves are concerned, Fig.7 gives the -T functions which are comparative altitude distances for comparison curve performance changes following along with target background temperature differences. From the Fig., it is possible to see that, when ΔT is within 10km, it intersects at approximately 8km, that is, within 8km. 3 - 5 micron performance and Milton's conclusions are relatively close. The conditions are: oceanic weather Lowtran6, temperature 27°C, humidity 19g/m-3 . The 3 - 5 micron detector device is $\mathrm{InSb}D_{\lambda}^{*}=10.2\times10^{10}$, Optical aperture is 100mm. For 8 - 12 microns, it is $MCTD_{\lambda}^{*}=5.6\times10^{10}$, Other conditions are the same.

(4) As far as James' comparison curves are concerned, Fig.8 is comparative results given by James for two wave bands in fixed view systems. Curves in the Fig. use effective noise temperature differences in order to judge the quality of performance. /8
Atmospheric influences are not considered. The 4 curves in the Fig. represent different wave band states for three

types of InSb, HgCdTe, and SiGa devices. Curves clearly show that, when background temperatures are above 230K, 3 - 5 micron InSb performance exceeds 8 - 12 microns.

From the various types of analysis above, it is possible to see that, when detection device D* approaches background limits, 3 - 5 micron wave band performance is better than 8 - 12 microns.

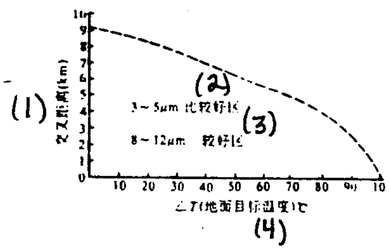


Fig.7 Relative Performance Crossing Distance Curves Varying Along with Ground Target Temperature Changes (1) Crossing Distance (2) Comparatively Good Area (3) Relatively Good Area (4) Ground Target Temperature

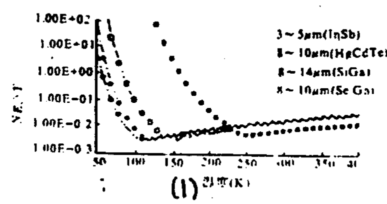


Fig.8 Relationships of NEΔT for Detection Devices Listed and Background Temperatures (1) Temperature

## IV. COMPREHENSIVE COMPARISONS AND CONCLUSIONS

### (I) Comparisons

#### (1) Radiation Data

From data in Chapter III, Section II(1), it is possible to know that: the radiation density ratio of 300K black body 3 - 5 micron wave bands versus 8 - 12 microns is 1:26.6, the derivative ratio of radiation density to temperature is 1:9.3, and the contrast ratio is 1:0.45. Following along with background temperature (target temperature is higher than background temperature by $\Delta T$) these specific values increase. At 500K, radiation densities and the derivatives versus temperature of the two approach.

#### (2) Detection Devices

With regard to $D_{\lambda}^{*}$, of 300K background limit detection devices, 3 - 5 microns is over 10 times higher than 8 - 12 microns. Also, because the manufacture of detection devices which reach (approach) background limit levels is easy, and 8 - 12 microns meets with a good number of difficulties, the specific values associated with practice can be higher. For example, under present conditions, as far as conditions where U.S. satellite sensor BMAP pick up system parameters are completely the same are concerned, system equivalent noise power NETD and noise equivalent temperature differences are respectively:

$$NETD_{3.9\sim4.8\mu m}=6\times 10^{-15}(W/cm^2),$$
$$NEP_{7.6\sim 11.3\mu m}=1.1\times 10^{-3}(W/cm^2);\quad NEP_{3.9\sim 4.8\mu m}=0.01(K);\quad NEP_{7.6\sim 11.3\mu m}=0.02(K).$$

(Background test measurements on 300K group.)

(3) Theoretical Relative $SNR_{rel}(\Delta\lambda)$

(Not considering atmospheric transmission influences, theoretical values for optical modulation transmission functions with $\zeta=2$ .)

| (1) 波 段 | $8\sim12\mu m$ | $3\sim5\mu m$ | $3.5\sim5\mu m$ | $3.4\sim4.1\mu m$ |
|---|---|---|---|---|
| $SNR_{rel}(\Delta\lambda)$ | 1 | 1 | 0.684 | 0.294 |

(1) Wave Band

(4) Atmospheric Transmission Characteristics

North of the middle latitudes (referring to the northern hemisphere), differences in atmospheric penetration properties between two wave bands are not great. In the south--particularily in the tropics--summer 8 - 12 micron atmospheric horizontal attenuation is greater than 3 - 5 micron by 0.5dB/km or more. In the 1970's, in the area of China's Hainan Island, tests clearly showed that, in the case of 8 - 12 microns, winter and summer attenuations differed from each other by 0.4 - 0.6 dB/km. This point was empirically verified with oblique paths seen in actual situations. /9

(5) Target Background Radiation Contrasts

3 - 5 micron wave band targets above 300K are all higher than 8 - 12 micron wave bands.

(6) With regard to penetration capabilities through battlefield smoke, 8 - 12 micron wave bands are better than 3 - 5 micron wave bands.

(7) Cost prices of 3 - 5 micron detection devices and optical systems are lower than 8 - 12 microns.

(8) With regard to high temperature backgrounds (targets), 3 - 5 micron performance is better than 8 - 12 microns. For low temperature backgrounds (targets), by contrast, the opposite is true. At the levels of current instruments (referring to fixed view systems), crossing points are in the vicinity of 230K.

(II) Several Conclusions

(1) Considering battlefield smoke: in the north, imagery systems opting for the use of 8 - 12 microns are better; however, in the south--particularly the tropics--systems opting for 3 - 5 microns are better.

(2) The prices of 3 - 5 micron systems are generally lower than the prices of 8 - 12 microns.

(3) With regard to automatic acquisition and tracking systems (that is, systems with no people participating)--because of better contrast--opting for the use of 3 - 5 microns is easier for identification, acquisition, and tracking.

(4) When targets and backgrounds are high temperature, opting for the use of 3 - 5 micron imagery systems is better.

(5) Considering the influences of aerodynamic heating of nose covers of high speed flying objects, it is better to select the use of 3 - 5 microns with all large aerodynamic heating influences.

(6) Opting for the use of dual wave band systems (8 - 12 microns and 3 - 5 microns), it is possible to increase system adaptability. Moreover, it is advantageous for target recognition.

(7) China should increase 3 - 5 micron fixed view system technology development, at the same time, developing dual wave band imaging systems.

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